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(6) CLUSTERING EDGE VALUES FOR
THRESHOLD SELECTION.

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ABSTRACT

Thresholds may be chosen for images containing several object classes by clustering thinned edge points in a 2-D histogram, whose axes represent gray level value and edge value. Each such edge cluster suggests its average gray level as a threshold. Interior clusters may also be defined as representatives of object class interiors. The relation of edge clusters to interior clusters gives rise to a classification strategy based on partitioning the 2-D histogram into disjoint regions labelled as to object class. Each partition is a classification domain for points of the original gray level image.

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1. Introduction

A variety of methods for selecting thresholds are known [1]. Many of them attempt to deduce the best threshold by studying properties associated with points on the boundary between object and background. Thus if the object is substantial and contrasts with the background, then the image's gray level histogram will exhibit a valley at the gray level associated with border points. More complicated schemes study the cooccurrence of high edge value and gray level as represented by a two-dimensional histogram. It has been shown that for images containing one object class and one background class, the average gray level of high edge value points predicts a good threshold [2]. This scheme, however, fails for images having several object classes, since high edge values may arise from the adjacencies among several gray level populations each requiring a different threshold. In what follows, we present an approach to thresholding in a multi-population environment.

2. Edge detection and thinning

Our approach is to produce clusters of points corresponding to region borders and to associate the average gray level of each cluster with a threshold for the corresponding region. Region borders usually correspond to points of locally maximum edge response. Our previous work suggests the use of edge detectors which select at each point the maximum difference of averages of adjacent neighborhoods over several directions [3]. By suppressing non-maximum responses normal to the selected direction (i.e., across the edge), thin contours result which appear to surround object regions. Figure 1b shows unthinned edge detector response; Figure 1c illustrates the results of thinning using non-maximum suppression.

This process produces as a by-product points with very low edge value, including values which truncate to zero. Such points correspond to the interiors of homogeneous regions. It is useful to include such points in our analysis, even though they constitute a population with fundamentally different properties from contour points. Figure 2 illustrates thinned detector responses with region interior maxima included.

3. Construction of a two-dimensional histogram

Once the thinning has been accomplished, the resulting parts can be accumulated in a two-dimensional histogram. The 2-D histogram consists of two labeled coordinate axes. The horizontal axis represents the gray level value of the point; the vertical axis represents the edge value. Each point which survives the thinning procedure is accumulated in the histogram at its (gray level, edge value) coordinates. Figure 3 shows examples of images together with their 2-D histograms.

Consider the noisy synthetic image in Figure 3a and its 2-D histogram in Figure 3b. The three clusters lying along the top of the histogram have very low edge values. These clusters are centered at gray levels 20, 30, and 40 from left to right and represent interiors of the three distinct regions of the picture. The cluster lying between gray levels 30 and 40 and centered at edge value 8 represents the boundary between the inner disk and the surrounding annulus. Similarly the cluster lying between gray levels 20 and 40 and centered at edge value 15 represents the boundary between the annulus and the background. The three clusters at the top of the 2-D histogram are called interior clusters since they represent the interiors of regions. The other two clusters are called edge clusters since they represent boundaries between regions.

In practice, it was found that the gray level of a thinned edge point does not serve as a good coordinate for the 2-D histogram. Specifically, for a step edge, the gray level of an edge point lies in one population or the other but not at any intermediate gray value. The profile of a sharp edge is shown in Figure 4a. If an edge operator is applied such that the difference of neighborhoods A and B is calculated, the gray level of the points will have either the value of the points in A or the value of the points in B. Therefore the 2-D histogram will be as shown in Figure 4b. The sharp edge is not displayed as a cluster, but rather as two spikes where one spike is plotted at gray level a for points in A and the other at gray level b for points in B. Figure 5 shows a test pattern and the 2-D histogram resulting from accumulating points based on gray level and edge value. Note that the histogram consists of a pair of spikes corresponding to the gray levels on either side of the step edge.

In order to merge the two spikes into a single cluster for sharp edges, the gray level coordinate of the 2-D histogram is replaced by the average gray level across the direction of the edge. Since edge value is obtained as usual by differencing over neighborhoods, the average gray level is obtained by computing average gray level over these same neighborhoods. In this way points near neighborhoods A and B of Figure 4a will be mapped near $\frac{a+b}{2}$ as shown in Figure 4c. Figures 5c and 6c show the effect on the 2-D histogram of using the average gray level instead of the point gray level.

In addition to creating clusters from values at sharp edges, the 2-D histogram using averaging will also tend to make clusters more compact in the direction of the horizontal axis. The reason can be illustrated by the profile of an edge shown in Figure 7. In a 2-D histogram not using averaging, the point x will get mapped into gray level z. However, since the neighborhood A contains points where the edge ramp begins to level off, the value $\frac{a+b}{2}$ will be greater than z and therefore points near x will be mapped at higher gray level values in the 2-D histogram using averaging. The reverse happens for points near the top of the ramp, i.e., they will get mapped to lower gray level values. Therefore the cluster tends to contract in the horizontal direction since points are mapped closer to the center of the cluster.

It is important to note that the size of a cluster (i.e., the number of points in it) is closely related to properties of the region it describes. Thus interior clusters relate both to the area of the region and to the size of the neighborhood over which the local operations (edge detection, non-maximum suppression) are defined. For small object regions, there may be no points sufficiently far from the object boundary to resist suppression. Thus interior clusters may be indistinguishable from noise, or may be nonexistent.

Clusters of points at higher edge values are more likely to be significant (based on our homogeneity assumptions). The size of an edge cluster is therefore related to the perimeter of the surrounded region in the image. Since perimeter increases (roughly, for digital images) as the square root of area, the edge clusters for objects of moderately different areas should, nonetheless, be of comparable size. A priori estimates of size are of use in discriminating true edge clusters from random noise.

4. <u>Relationships between clusters in a 2-D histogram</u>

Consider the edge cluster in Figure 8 whose centroid is (e,g). The value g is approximately equal to the average gray value of the edge ramp along the contour between the two interior regions. The value e is approximately equal to the average thinned edge response along this contour. It is limited by the height of the edge ramp, i.e., in general, it will not exceed the value of this height. Furthermore, the value of e depends on the relationship between the width of the edge ramp and the neighborhood size used by the edge operator. If the neighborhood size is less than the edge ramp width, the value of e will be less than the edge ramp height (see Figure 9a).

The edge cluster in Figure 8 serves as the boundary separating two regions of average gray level g-e/2 and g+e/2 in the original image. This relation of an edge cluster to two interior clusters has several consequences. Finding two interior clusters at gray levels g-e/2, g+e/2, respectively, would serve as confirmation of this assertion. Conversely, to determine whether two regions with average gray level g_1, g_2, respectively, share a common boundary (i.e., are adjacent), one could attempt to locate an edge cluster with centroid $(|g_2-g_1|, (g_1+g_2)/2)$, as in Figure 10. Finally, finding an edge cluster with centroid (e,g) and one interior cluster at gray level g-e/2 (see Figure 8) would serve to suggest another interior cluster at gray level g+e/2. If this cluster is not present in the histogram, we can hypothesize its existtence. It may be indiscernible either because the interior region has no points with near-zero gradient or the interior cluster cannot be separated from another cluster.

In general, however, $e < |g_2-g_1|$, i.e., the average edge value of edge clusters is somewhat lower than predicted. Figure 9b shows the edge ramp and neighborhoods at P over which the edge values are computed. Note that the average value a (over A) is generally less than the value of g_2, while the average value b (over B) is generally greater than the value of g_1. Thus, in general, $|a-b|<|g_2-g_1|$. We can now more accurately predict the location of cluster centroids based on a knowledge of the edge ramp and the edge detector. Thus, for an edge detector using differences of averages over $s \times s$ neighborhoods and for a linear edge ramp of height h and width w, the expected maximal edge response is $h - \frac{w \cdot h}{4 \cdot s}$. Whereas h is normally unconstrained, w, the ramp width (or edge fuzziness), is fairly constant within an image and therefore the edge operator size s should be chosen so that $\frac{w}{4s}$ is small.

5. Cluster extraction

We have investigated some simple methods of cluster extraction, and we now describe one which has been moderately successful. First, use the histogram of thinned edge values (which is nothing more than the projection of the 2-D histogram on the edge axis) to detect edge value ranges containing significant peaks. Many 1-D histogram segmentation schemes exist [1]. A conservative method is best. Each of these ranges corresponds to a horizontal strip across the 2-D histogram (see Figure 11).

For each strip, construct a standard gray value histogram, i.e., project each individual strip onto the x-axis. Segment each such histogram as before according to its peaks. Each such segment corresponds to a rectangle in the original 2-D histogram (Figure 11). Clusters are associated with well-populated rectangles. Thresholds may then be computed as average gray levels within clusters.

6. Coordinating multiple thresholds

Given a set of thresholds for an image obtained by locating the centroid gray levels for the edge clusters, it is unclear how one applies them in general. For example, consider the drawing in Figure 12a and its 2-D histogram, Figure 12b. The center of the edge cluster belonging to the interior clusters at gray levels 30 and 40 is at gray level 35; while the edge cluster separating the interior clusters at 20 and 40 has 30 as its center. Thus the thresholds are 30 and 35. The threshold at 30 will optimally separate the background from the outer boundary of the ring; however, it will cause the hole in the ring to break up in a random fashion. The threshold at 35 will in fact separate the hole from the ring but will assign too many border points of the 20-40 border to the background region. Thus neither threshold is by itself optimal.

A solution to this problem can be obtained by partitioning the 2-D histogram into disjoint regions which are labeled as to object class (Figure 13). Thus all points in the original image as (opposed to thinned points only) would be classified based on the feature pair (gray level, edge value). The location of each feature pair in the partitioned histogram would determine the object class to which each image point belongs. Note that each half of an edge cluster belongs to a different interior cluster (see the arrows in Figure 13). A simple algorithm to perform this partitioning on a complete well-formed 2-D histogram is as follows:

Draw vertical lines midway between each adjacent pair of interior clusters. The lines extend to the bottom of the histogram. Starting at the lowest edge value edge cluster, draw a vertical line bisecting the cluster and extending from just above the cluster to the bottom of the histogram. Draw the (horizontal) perpendicular to the cluster bisector at the endpoint just above the cluster and extend it until it meets the vertical on each side. Delete each of those verticals below the points of intersection. Repeat for clusters at higher edge values.

Each vertical line either separates two interior clusters (thus identifying points on either side of the line as to cluster class name) or bisects an edge cluster (with points on each side being labeled by the appropriate class name of the two associated with each cluster).

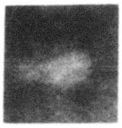
There are images for which this partitioning scheme does not assign a unique class name to each partition region. Consider the drawing in Figure 14a and its 2-D histogram in Figure 14b. When a partitioning of the histogram is attempted, region X is labelled by both class 20 and class 30. This occurs because there is an actual ambiguity in the (edge value, gray level) classification space, since points at gray level 25 and edge value 20 exist both on the 10-30 boundary and on the 20-40 boundary. This conflict can be resolved arbitrarily by dividing X in half and assigning the left half to class 30 and the right half to class 20. Note, however, that disjoint partitions of the 2-D histogram may be associated with the same class name. Perhaps a better solution is to avoid classifying points near ambiguous regions of the 2-D histogram until it can be done by some other method such as proximity to already labelled points in the original image.

References

1. A. Rosenfeld and A. C. Kak, Digital Picture Processing, Academic Press, New York, 1976.

2. J. S. Weszka, R. N. Nagel, and A. Rosenfeld, A threshold selection technique, IEEE-TC-23, 1974, 1322-1326.

3. Algorithms and Hardware Technology for Image Recognition, First Semi-Annual Report on Contract DAAG53-76C-0138, Computer Science Center, University of Maryland, College Park, MD, October 1976.

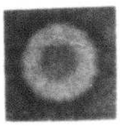
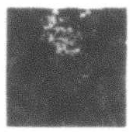
  

(a) (b) (c)

Figure 1a. FLIR window containing tank.
b. Edge detector response (thresholded).
c. Thinned edge detector response (thresholded).

(a)  (b) 

Figure 2a. LANDSAT window (Monterey, CA).
b. Thinned edge detector response (thresholded).

(a) (b) (c) (d)

(e) (f)

Figure 3a. Disk (gray level 30) within ring (gray level 40) within background (gray level 20).
b. 2-D histogram of (a) with gray level as x-axis (increasing from left to right) and edge value as y-axis (stretched -- increasing from top to bottom). Interior of background is leftmost, topmost cluster.
c. Window containing house.
d. 2-D histogram of (c).
e. Window containing tank.
f. 2-D (stretched) histogram of (e).

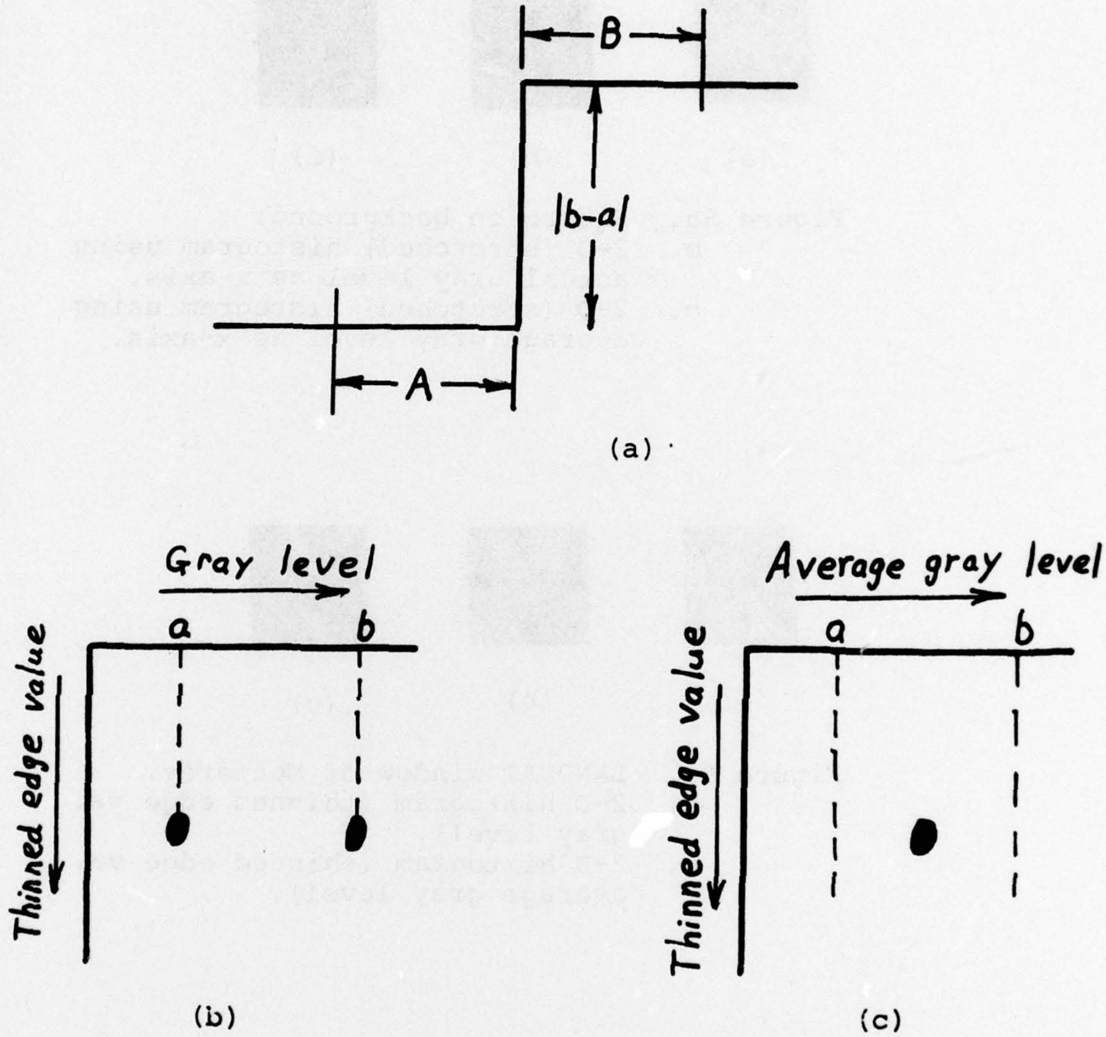
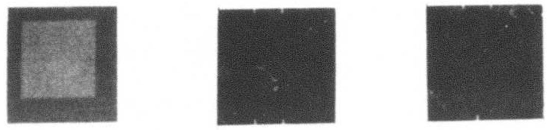


Figure 4a. Profile of a step edge. A and B are two neighborhoods of the same size with average gray levels a and b, respectively.

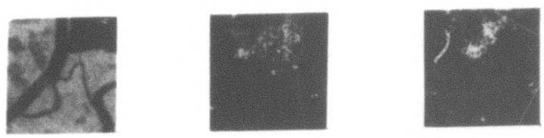
b. 2-D histogram (thinned edge vs. gray level).

c. 2-D histogram (thinned edge vs. average gray level).



(a) (b) (c)

Figure 5a. Square on background.
b. 2-D (stretched) histogram using actual gray level as x-axis.
c. 2-D (stretched) histogram using average gray level as x-axis.



(a) (b) (c)

Figure 6a. LANDSAT window of Monterey.
b. 2-D histogram (thinned edge vs. gray level).
c. 2-D histogram (thinned edge vs. average gray level).

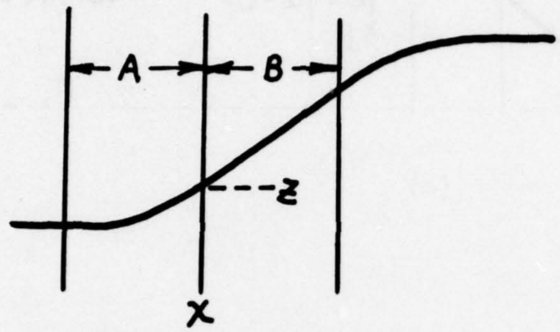


Figure 7. Profile of an edge. A and B are two neighborhoods of the same size with average gray levels a and b, respectively.

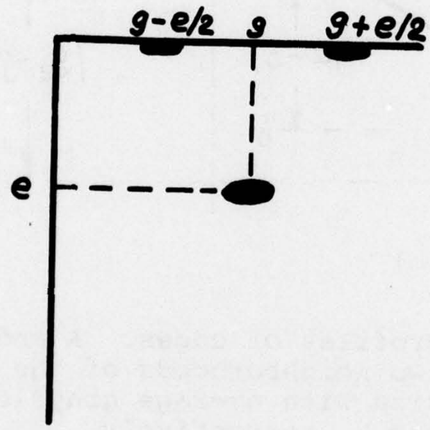
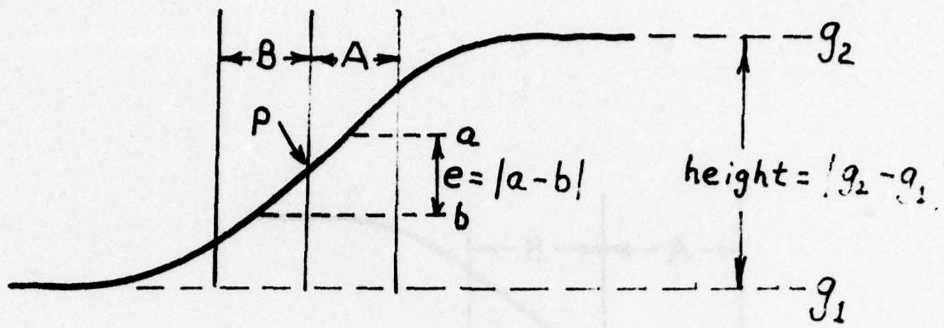
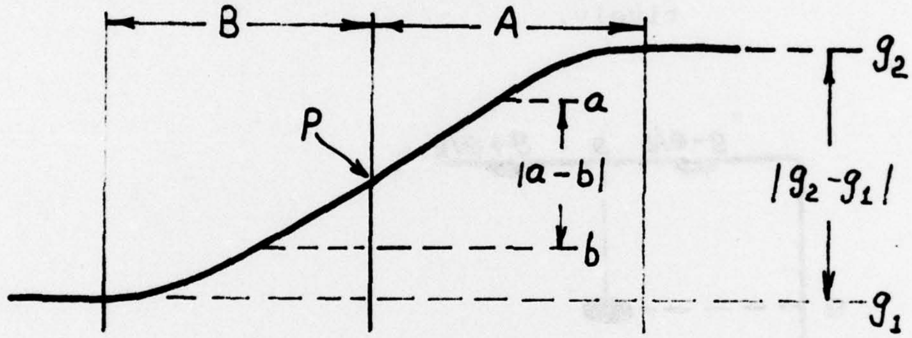


Figure 8. 2-D histogram of an image consisting of two distinct homogeneous regions.



(a)



(b)

Figure 9. Profiles of edges. A and B are two neighborhoods of the same size with average gray levels a and b, respectively.

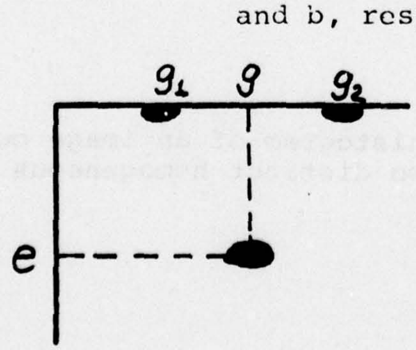


Figure 10. 2-D histogram of an image consisting of two distinct homogeneous regions.

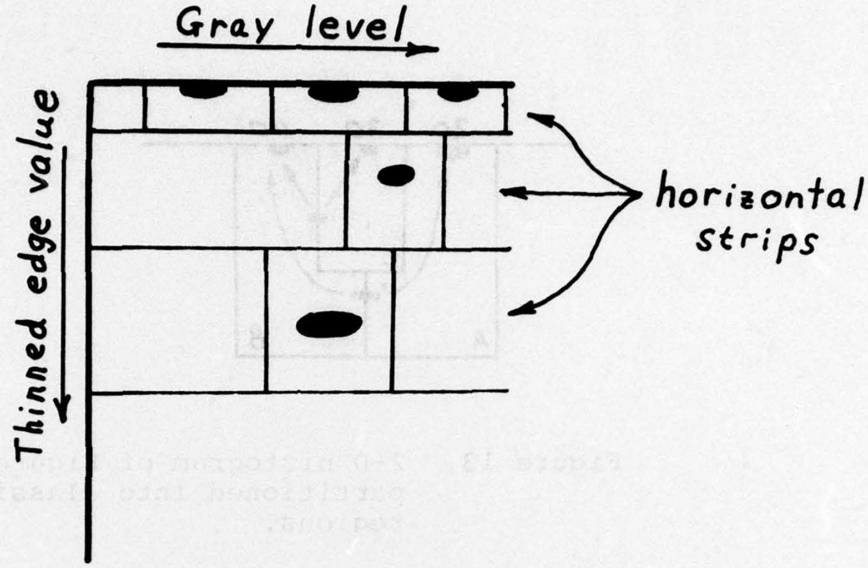
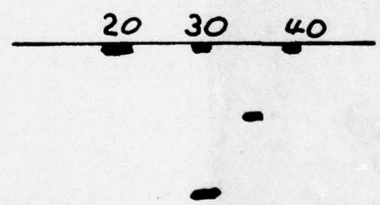


Figure 11. 2-D histogram of the image in Figure 3a. The horizontal strips and rectangles constructed for cluster extraction are shown.



(b)

Figure 12a. Adjacent object regions on background (same as Figure 3a).
b. 2-D histogram for (a).

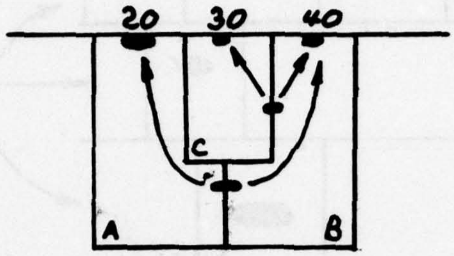
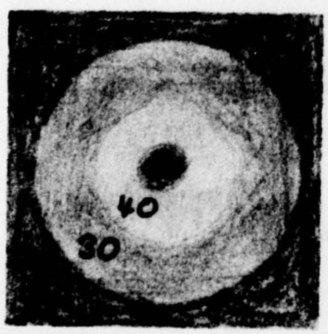
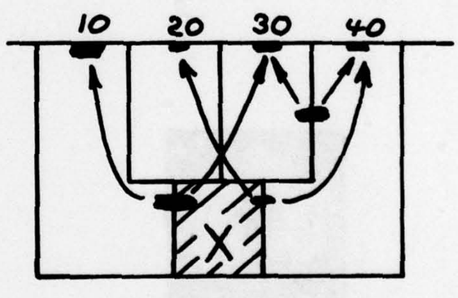


Figure 13. 2-D histogram of Figure 12a, partitioned into classification regions.



(a)



(b)

Figure 14a. Circular regions on background.
b. 2-D histogram, partitioned into classification regions.

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Abstract, cont'd.

2-D histogram into disjoint regions labelled as to object class. Each partition is a classification domain for points of the original gray level image.